Evaluation of 300 Minimally Invasive Liver Resections at a Single Institution

Less Is *More*

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Objective: We present the largest, most comprehensive, single center experience to date of minimally invasive liver resection (MILR).

Summary Background Data: Despite anecdotal reports of MILR, few large single center reports have examined these procedures by comparing them to their open counterparts.

Methods: Three hundred MILR were performed between July 2001 and November 2006 at our center for both benign and malignant conditions. These included 241 pure laparoscopic, 32 hand-assisted laparoscopic, and 27 laparoscopy-assisted open (hybrid) resections.

These MILR were compared with 100 contemporaneous, cohort-matched open resections. MILR included segmentectomies (110), bisegmentectomies (63), left hepatectomies (47), right hepatectomies (64), extended right hepatectomies (8), and caudate lobe (8) resections. Benign etiologies encompassed cysts (70), hemangiomata (37), focal nodular hyperplasia (FNH) (23), adenomata (47), and 20 live donor right lobectomies. Malignant etiologies included primary (43) and metastatic (60) tumors. Hepatic fibrosis/cirrhosis was present in 25 of 103 patients with malignant diseases (24%).

Results: There was high data consistency within the 3 types of MILR. MILR compared favorably with standard open techniques: operative times (99 vs. 182 minutes), blood loss (102 vs. 325 ml), transfusion requirement (2 of 300 vs. 8 of 100), length of stay (1.9 vs. 5.4 days), overall operative complications (9.3% vs. 22%), and local malignancy recurrence (2% vs. 3%). No port-site recurrences occurred. Conversion from laparoscopic to hand-assisted laparoscopic resection occurred in 20 patients (6%), with no conversions to open. No hand-assisted procedures were converted to open, but 2 laparoscopy-assisted (7%) were converted to open.

Conclusion: Our data show that MILR outcomes compare favorably with those of the open standard technique. Our experience suggests that MILR of varying magnitudes is safe and effective for both benign and malignant conditions.

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Minimally invasive liver resection (MILR) represents a natural extension of the continued evolution of minimally invasive surgery in general and laparoscopic liver surgery in particular. The growing experience with laparoscopic procedures, the ongoing technological advances in laparoscopic devices, and an increased patient awareness of the availability of these techniques have created an evolving interest in the application of these techniques to liver surgery and liver resection.[1] The surgical skills required for MILR have evolved in parallel with the adaptation of laparoscopic techniques to these procedures. Whereas laparoscopic ablative procedures require laparoscopic surgical skills that may include operative ultrasonography and liver mobilization, they typically do not necessitate either hilar dissection or parenchymal transection.[2,3] In contrast, laparoscopic approaches to liver cysts[4–6] and wedge resection of peripheral solid tumors[7–9] may require more aggressive mobilization of the affected hemiliver(s) and transection of liver parenchyma and, therefore, are more technically demanding and potentially more hazardous. Anatomic hemihepatectomies require a clear understanding of liver anatomy, experience with liver surgery, and, additionally, the ability to deal laparoscopically with major vascular and biliary structures, both outside the parenchyma of the liver and during parenchymal transection.[10]

Finally, both segmental and sectional resections performed laparoscopically can be more technically demanding than hemihepatectomies, given that these are often performed without inflow control at the hilum and also because the area of parenchymal transection can be quite extensive. Hand-assist during these laparoscopic procedures can afford several benefits that include the ability to use the surgeon's hand to help stabilize and mobilize the liver and, in cases of hemorrhage, the use of temporary digital control by the direct application of pressure.[11] Despite these technical challenges, MILR has been used increasingly in the management of liver tumors over the past decade.

Beginning in 1993, the Division of Transplantation at Northwestern Memorial Hospital has been involved in the care of patients with hepatobiliary pathology, such as benign and malignant liver tumors. Standard open surgical techniques were used exclusively until the late 1990s. When the minimally invasive liver surgery program was instituted by one of the authors (A.K.) in 2001, a database was initiated that has registered the details of each case performed regardless of surgical approach. The database is not limited to liver resections and also includes other minimally invasive liver surgery such as laparoscopic ablation of liver tumors and is maintained in real-time. In this study, we will report on the evolution of MILR at our center and review and evaluate our collective experience with these procedures.

PATIENTS AND METHODS

Using the aforementioned database, and with appropriate approvals from our Institutional Review Board, we retrospectively reviewed the recorded data and hospital records from 300 consecutive patients who underwent MILR between July 2001 and November 2006. To compare MILR to traditional open liver resections, we compared these 300 cases to contemporaneous open resections also accessed from the database, attempting to match for age, type of resection, benign versus malignant etiology, and the presence or absence of cirrhosis. MILR included 241 pure laparoscopic, 32 hand-assisted laparoscopic, and 27 laparoscopy-assisted open resections.[12,13]

Pure Laparoscopic Resection (PLR)

In the case of anterior or left liver lesions, the patient is placed supine. For posterior lesions of the right liver, the patient is placed in the left lateral decubitus position allowing access to the midline. A 12-mm umbilical port is used for the 30 degree laparoscope. Additional working ports are placed strategically to optimize manipulation and mobilization of the liver. Port sites are placed in anticipation of open conversion so that the port sites are in line with standard surgical incisions, if needed. After laparoscopic inspection of the liver and lesion of interest, laparoscopic liver ultrasound is used to demarcate surgical tumor resection margins, identify potentially hazardous intrahepatic vascular or biliary structures, and to rule out synchronous lesions.

The liver resection proceeds with mobilization, vascular control, parenchymal transection, cut surface inspection, and specimen extraction. Inflow occlusion is used only for hemihepatectomy, usually by applying a bulldog clamp to the ipsilateral portal vein branch, after division of the overlying hepatic artery. Hepatic venous control is used for hemihepatectomy in case of hemorrhage or gas embolism. Parenchymal transection is then performed once laparoscopic sutures, vascular clamps, and optimal visualization are readied. In the beginning of our experience, we used endoscopic ultrasonic shears (AutoSonix Ultrasonic Coagulator, US Surgical Corporation, Norwalk, CT) for mobilization, hilar dissection and occasionally for hepatic parenchymal transection, and stapling devices were used liberally for parenchymal transection. Currently, a bipolar coagulating/cutting device (LigaSure, Valley Laboratory, Boulder, CO) has become our instrument of choice for mobilization due to its ability to both separate tissues and seal vessels, (eg, small venous branches from the liver to the vena cava). We have found saline-linked cautery (Tissue Link EndoSH2.0 Sealing Hook) to be the method that most reliably transects the hepatic parenchyma in our hands. Using this device the liver tissue is precoagulated allowing almost bloodless transection, leaving intrahepatic vessels to be divided with scissors or either by the LigaSure device or endoscopic vascular staplers when complete precoagulation is in doubt. For hemihepatectomy, the portal vein/hepatic duct and hepatic vein are stapled and divided at the end of transection to ensure the integrity of the remnant liver vascular and biliary structures. For completion hemostasis, saline-linked cautery, Argon Beam coagulator, and/or topical hemostatic agents may be of use. Great caution is taken when using the Argon Beam coagulator because of the risk of gas embolism unless concomitant suction and venting is used.[14–16] Once the specimen is ready for extraction, in cases of benign lesions, it is morcelized inside an internalized impermeable bag and removed piecemeal through the umbilical laparoscopic port. In cases of malignant lesions, the umbilical incision is extended at the fascial level to allow for extirpation of the intact specimen using an extraction bag.

Hand-Assisted Laparoscopic Resection (HALR)

The positioning of the patient is similar to that for the pure laparoscopic approach. In contrast to PLR, a small incision is used to allow access of the hand for surgical maneuvers and specimen extraction. We prefer to use prior incisions (for cosmetic reasons) or the umbilicus as even small transumbilical incisions appear minute postoperatively. A hand-port, videoscope port, and additional ports are placed strategically to optimize manipulation and mobilization of the liver. As in PLR, laparoscopic ultrasound is used liberally to demarcate surgical tumor resection margins, identify potentially hazardous intrahepatic vascular or biliary structures, and to rule out synchronous lesions.

The liver resection proceeds with the same choreography as PLR, however, the hand is used liberally for mobilization, retraction, and direct pressure if necessary and for extraction. In some cases, the hand can be removed and the hand-port can be used to insert a laparoscopic instrument if one is needed in the epigastric position. Most importantly, the hand-assist incision is used for extraction of malignant lesions to prevent rupture of the specimen.

Laparoscopy-Assisted Open Resection—Hybrid (LAOR)

The supine position is used exclusively. This technique is similar to the hand-assisted procedure but portions of the surgical approach resemble more that of open techniques. An epigastric incision is made 2 cm below the xiphoid process for hand-assistance and specimen extraction.[12,13] The teres, falciform, and coronary ligaments are divided and the surgeon's left and right hands are sequentially used for palpation of the liver and abdominal exploration, especially in the case of malignant tumors. If there are adhesions to the abdominal wall from previous surgery, these are released from the circumference of the hand-assist site under direct vision using standard open technique. At this point, an umbilical port is inserted for the laparoscope and an additional port placed in the right lower quadrant (if target lesion in right hemiliver) or left lower quadrant (left hemiliver lesions). Once both ports are placed, the surgeon removes his/her right hand from the abdominal cavity and a hand-port is placed in the epigastric incision. The abdominal cavity is insufflated, videoscope is inserted through the umbilical port, and the hand-assisted laparoscopic mobilization of the target hemiliver is performed using either a bipolar coagulating/cutting device (LigaSure Valleylab, Boulder, CO) or the Autosonic scalpel (Tyco, USSC), which is inserted through the lower quadrant port. During right hepatectomy this includes the right triangular, hepatorenal, and coronary ligaments. Also, the areolar tissues of the bare area of the liver are taken down with a combination of blunt dissection with help from either instrument. To facilitate this dissection, the surgeon uses his/her right hand through the hand-port to retract the liver superiorly, medially, or inferiorly as needed. On occasion, the camera is switched to the lower quadrant port and the dissecting instrument can be placed through the umbilical port, or alternatively, the hand can be removed from the hand-port, and the dissecting instrument can be inserted through the hand-port. Once the inferior rena cava (IVC) is visualized and the right hemiliver is fully mobilized, the cholecystectomy, hilar dissection, and initial parenchymal transection can be performed to the comfort level of the surgeon, given laparoscopic expertise and patient anatomy. Once safety or surgeon comfort is in question, the hand-assisted laparoscopic portion of the procedure ends. The patient is rotated back to neutral position. The pneumoperitoneum is relieved, the ports are removed, including the hand-port, and a mechanical retractor used to achieve optimal visualization of the hilum and/or transection plane.

The epigastric incision can be extended if the body habitus makes exposure difficult. At this point, if needed, the remaining hilar dissection is performed under direct vision using standard open techniques. Laparotomy pads or sponges are placed behind the liver as needed to optimize the exposure or bring the proposed transection line into view as in standard open cases. Any additional mobilization of the right hemiliver, including dissection of the lobe away from the IVC and dissection of the right hepatic vein can be done at this point, as needed. Once the preparatory work is completed, parenchymal transection is performed under direct vision, using the surgeon's preferred techniques and devices for either lobar or segmental resections. We have found that the right hemiliver, especially segments V, VI, and to a certain extent VII, can be easily exteriorized and the resections can be performed having delivered the target segment through the epigastric incision. In the case of right hemihepatectomy, a tape can be placed behind the liver to perform the hanging maneuver as described by Belghiti.[17] This maneuver facilitates transection of the posterosuperior parenchyma. We have used laparoscopic stapling devices liberally for dividing inflow pedicles and hepatic veins, although standard clamping and sewing techniques are also applicable using this approach.

For procedures involving the left hemiliver, the approach is altered slightly. The surgeon's left hand can be used to manipulate the left lateral section and the dissecting instrument is placed through the left subcostal port. The left triangular ligament is divided, as is the hepatogastric ligament. The left hepatic vein is visualized, hilar dissection performed (if necessary) to comfort level of surgeon, and then the laparoscopic instruments/devices are removed and the procedure continues using standard open techniques. Again, laparoscopic stapling devices are used liberally for inflow pedicle and hepatic vein division. The specimen is extracted through the epigastric incision.

RESULTS

Standard nomenclature was used to describe the type of resection.[18] Within the 300 cases in the MILR group, there were 110 segmentectomies, 63 bisegmentectomies, 47 left hemihepatectomies, 64 right hemihepatectomies, 8 right trisectionectomies, and 8 caudate lobe resections. Of these, the majority consisted of PLR (241) with 32 HALR and 27 LAOR. The MILR were compared with 100 case-matched, contemporaneous open resections (Table 1).

There were 197 MILR performed for benign indications, including 20 live-donor right hemihepatectomies, and 103 for malignant indications. Benign etiologies encompassed cysts (70), hemangiomata (37), FNH (23), adenomata (47), and 20 live donor right hemihepatectomies. Malignant etiologies included primary (43) and metastatic (60) tumors. One hundred seventy-five PLR were performed for solid lesions. One hundred eleven PLR consisted of formal hemihepatectomies, 63 of which were performed for solid lesions (Tables 2 and 3).

Hepatic fibrosis/cirrhosis was present in 25 of 103 (24%) of the patients undergoing MILR for malignant lesions By design, these parameters were comparable in the open cohort (Table 4). Interestingly, although no MILR patient with cirrhosis developed clinically significant hepatic decompensation, we noted subjective complaints of prolonged postoperative fatigue. In contrast, 2 patients in the open cohort

TABLE 1. Type of Resection by Surgical Technique Utilized

	PLR	HALR	LAOR	MILR Total	Open
Segmentectomy	108	0	2	110	38
Bisegmentectomy	60	2	1	63	10
Left hepatectomy (Sg 2–4)	37	10	0	47	12
Right hepatectomy (Sg 5–8)	29	12	23	64	38
Right trisectionectomy (Sg 4–8)	0	8	0	8	3
Caudate lobectomy	7	1	0	8	1
Total	241	32	27	300	100

TABLE 2. MILR by Type of Lesion

	Benign Cystic	Benign Solid	Malignant	Other
Segmentectomy	34	32	44	0
Bisegmentectomy	9	28	16	0
Left hepatectomy	9	18	20	0
Right hepatectomy	9	24	11	20
Right trisectionectomy	4	4	0	0
Caudate lobectomy	1	4	2	0
Total	70	107	103	20

TABLE 3. Type of Lesion by Surgical Technique Used

	PLR	HALR	LAOR	Open
Benign cystic	66	4	0	2
Benign solid	93	10	4	21
Malignant	82	18	3	53
Other	0	0	20	20
Total	241	32	27	100

TABLE 4. Extent of Resection by Surgical Technique Used in Patients With Fibrosis/Cirrhosis

	PLR	HALR	LAOR	Open
Segmentectomy	12	1	2	2
Bisegmentectomy	4	1	0	1
Left hepatectomy	0	1	0	2
Right hepatectomy	2	2	0	2
Total	18	5	2	7

experienced decompensation severe enough to warrant liver transplantation (data not shown).

There was high data consistency within the 3 types of MILR, although operative times and length of stay (LOS) were higher for the LAOR cohort compared with PLR and HALR, possibly reflecting that 20 of 27 of these were living donor right hepatic lobectomies. These procedures require longer operative times because of intraoperative cholangiography, the lack of hilar vascular control, meticulous biliary transection, and the need to synchronize the hepatectomy with the recipient operation. Nonetheless, in the aggregate, MILR compared favorably with standard open techniques: operative times (99 vs. 182 minutes), blood loss (102 vs. 325 ml), transfusion requirement (2 of 300 vs. 8 of 100), length of stay (1.9 vs. 5.4 days), overall operative complications (9.3 vs. 22%), and local malignancy recurrence (2% vs. 3%). No port-site recurrences occurred. Mean follow up for benign and malignant diagnoses was 69 and 45 months respectively. Conversion from laparoscopic to hand-assisted laparoscopic resection occurred in 20 patients (6%), with no conversions to open. No hand-assisted procedures were converted to open, but 2 laparoscopy-assisted (7%) were converted to open (Table 5).

TABLE 5. Surgical Outcomes/Complications by Surgical Technique Used

	PLR (241)	HALR (32)	LAOR (27)	Open (100)
Operative time [mean (min)]	95	82	157	182
Blood loss [mean (cc)]	100	82	150	325
Transfusion [mean (units RBC)]	0	2	0	8
LOS [mean (d)]	1.7	2.1	3.4	5.4
Bile leaks (no. patients)	2	5	1	4
Conversion (no. patients)	20*	0	2	NA

*Conversion from PLR to HALR.

We also analyzed surgeon reimbursement for MILR versus open resection. Given that there are currently no procedural billing codes (CPT) specific for MILR, these procedures are often coded and billed as standard open procedures (CPT codes 47100, 47120, 47122, 47125 and 47130), with code 47379 as a modifier.[19] It is our practice to charge a percent premium added to the hepatectomy charge for the laparoscopic component. However, reimbursement depends on carrier-based decisions and therefore we wanted to analyze the reimbursement patterns for both Medicare and private party payors.

We first calculated the collection rate by resection type for both Medicare and private party payors by dividing actual reimbursement by our billed charges for both open and MILR cases. Given that our charges were higher for MILR because of the premium allocated to the 47,379 modifier, we then adjusted the collection rate to calculate the impact of MILR on revenue per procedure compared with the open cases, again by resection and payor types. We limited our analysis to partial and right hemiliver resections. We found that both the adjusted collection rates and the revenue were approximately the same for partial and right lobe resection from Medicare and private party payors, with a slight increase for MILR (1.25) in the revenue ratio for partial resections from private party payors. These differences were nonsignificant by Student *t* test comparison of means (Table 6).

There are sometimes concerns that laparoscopic procedures may result in additional hospital costs due to the need for laparoscopic instrumentation, and possibly longer operative times. However, these costs can be offset by shorter lengths of stay. Therefore, we analyzed operating room costs [(ORC) include costs of instruments, devices and operative time] and total hospital costs (THC) for 20 representative patients for MILR and compared them to 20 patients who underwent open resections. These cases were selected by eliminating outliers in both categories to analyze comparable groups. They were matched for age, type of lesion and other comorbid conditions, including absence of cirrhosis. Note that the mean LOS for the open group is lower than that for the entire open cohort because outliers from this group with LOS exceeding 5 days were not included in the analysis. Again, we performed this analysis for both partial and right lobe resections (10 each per group). We normalized for open resections. Therefore THC for open procedure for each type of resection is set at $1.00. This allows for a direct comparison with MILR. Because the focus is cost, we did not analyze reimbursement given that contractual agreements differ greatly between payors even within a single institution. We found that for partial liver resections and right hemihepatectomies, THC for MILR were 98% and 66%, respectively, of THC for open resection. Assuming equivalent reimbursement for individual payors, the net operating margin is higher for MILR, especially for right hemihepatectomy. It seems that the ORC for partial and right hemihepatectomy represent 39% and 36%, respectively, for open cases compared with 51 (0.50 of 0.98) and 47 (0.31 of 0.66) percent respectively for MILR. These differences were significant both for both partial ($P = 0.04$) and right hemihepatectomies ($P = 0.02$)

TABLE 6. Impact of MILR on Surgeon Revenue by Resection Type and Payor

Resection by Payor	Open Collection Rate (%)	MILR Collection Rate (%)	MILR/Open Charge Ratio	Adjusted MILR Collection Rate (%)	MILR/Open Revenue Ratio
Partial					
Medicare	41	29	1.43	42	1.02 (NS)
Private	65	52	1.55	81	1.25 (NS)
Right hepatectomy					
Medicare	44	27	1.50	41	0.93 (NS)
Private	67	42	1.53	64	0.96 (NS)

Data represent means of 40 representative patients (5 partial and 5 right lobe resections for each payor category for both MILR and open resection).

using Student *t* test. In contrast, non-ORC were 61% and 64% for open cases, and 49% and 53% for MILR. Linear regression showed that although no correlation existed between ORC and LOS, non-ORC as a variable dependent on LOS was highly significant ($P < 0.0001$) for all groups. Of interest, overall, standard deviations (variability) were much lower for MILR right hemihepatectomies compared with the other groups, despite the fact that representative open cases were selected by eliminating LOS outliers (Table 7).

DISCUSSION

Formal general surgery residency training in laparoscopic techniques began in the early 1990s and for several years was largely limited to cholecystectomy. Subsequently, in the mid 1990s, this training was extended to include other general surgical procedures such as splenectomy, gastric fundoplication, esophageal and other hollow viscous procedures such as small and large bowel resection.[20] Many of these procedures required bimanual laparoscopic skills, such as extensive mobilization of both intraperitoneal and retroperitoneal organs, intracorporal suturing and a better ability to control vascular structures and bleeding. The rapid evolution of these procedures and devices stimulated the emergence of advanced minimally invasive postgraduate fellowship training.

Two parallel developments caused us to initiate a program for MILR at our institution. First, our growing experience with laparoscopic live donor nephrectomy allowed us to accumulate a significant expertise and comfort with advanced laparoscopic techniques, such as the extensive laparoscopic mobilization of internal organs and laparoscopic vascular dissection.[21] Moreover, this valuable experience necessitated a dynamic familiarity with laparoscopic devices, at a time when these novel devices were being developed at a rapid rate. Second, in the mid to late 1990s, a few surgical groups began to report their experiences with MILR, consisting primarily of small series of laparoscopic resections of peripheral lesions, for the most part benign in etiology.[7,11,22,23] We were intrigued by these reports and therefore we made the decision to initiate a MILR program as part of our busy hepatobiliary practice. We began selecting patients with benign cystic lesions of the liver.[4] We subsequently included patients with peripheral solid benign lesions. Encouraged by our early results, we began to include malignant lesions, patients with fibrosis/cirrhosis, and larger magnitudes of resection. This early phase included only PLR. Finally, as a means to perform hemihepatectomies, HALR was employed until anatomic hepatectomies could be performed with certain patient safety, at which time we implemented the use of PLR for hemihepatectomies needed in resection of deeper lesions. Because of the nature of this evolution, we have continued to perform the majority of resections using PLR, unless safety or oncologic principles were in jeopardy. In these cases, we used HALR especially for the resection of larger malignancies or where vascular structures were adjacent to the lesion or surgical margin. In addition, we used either HALR or LAOR under 2 other circumstances. First, to allow the more senior surgeons who were not as comfortable with PLR to offer a minimally invasive approach to their patients and, second, to maximize patient safety as we adapted these techniques, particularly LAOR, to living donors (right hemihepatectomies). This hybrid technique (LAOR) was developed specifically for this use,[13] but has since been used when surgeon comfort level warrants its use.[12]

The current literature contains accounts of both PLR,[23] which seems to be preferred by some groups, whereas others use the hand-assisted approach.[11,24] Our center uses PLR whenever patient safety and oncologic principles allow, al-

TABLE 7. Hospital Costs by Resection Type and Surgical Technique Used

Resection Type	Technique	THC	ORC	Non-ORC	LOS
Partial	Open	1.00 (0.44)	0.39 (0.19)	0.61 (0.28)*	2.9 (0.9)
	MILR	0.98 (0.24)	0.50 (0.21) $P = 0.04$	0.48 (0.09)*	2.3 (0.5)
Right lobe	Open	1.00 (0.43)	0.36 (0.13)	0.64 (0.32)*	2.8 (1.3)
	MILR	0.66 (0.31)	0.31 (0.06) $P = 0.02$	0.35 (0.07)*	2.0 (0.7)

Data represent means and (standard deviation) of 10 representative cases for each category.
*$P < 0.0001$ (correlation with LOS).

though the preference is also surgeon-driven. Thus, in our series 80% (241 of 300) of resections were performed using PLR, with a large portion comprising benign lesions as testament to our conservative approach to malignancy, especially in our early experience.

Our data demonstrate that MILR outcomes compare favorably with those of open resections. MILR seems to be safe and effective in the treatment of both benign and malignant liver tumors. Specifically, both blood loss and transfusion requirements were notably lower in the MILR group compared with the open cohort. Moreover, biliary leak rates were similar in the MILR (8 of 300, 2.7%) and open (4 of 100, 4%) cohorts, with none requiring operative intervention. The incidence of bile leaks observed in our open cohort was similar to that reported in the literature.[25] Of interest, there was a relatively higher rate of bile leaks in the HALR cohort, perhaps reflecting the choice of instrument and technique used for parenchymal transection. Two MILR patients (HALR group) experienced incisional hernias, which compares favorably with the 20% 1-year incidence noted in open right hepatectomy in healthy liver donors[26] suggesting a benefit of MILR in terms of abdominal wall morbidity. In fact, the overall complication rate was lower for the MILR cohort (9.3% vs. 22%) and no MILR patient experienced significant hepatic decompensation, whereas 2 patients in the open cohort required liver transplantation for decompensation, and there were no operative mortalities in the MILR group. It is uncertain as to whether this observation is due to the difference in operative trauma or patient hepatic reserve. There were 103 MILR performed for malignant lesions compared with 53 open resections. 25 and 13 of these were for hepatocellular carcinoma, respectively. The size of the lesions and pathologic stages were similar between the 2 cohorts (data not shown). Despite previous concerns about the application of MILR to malignant cases, malignancy recurrence rates were also similar between MILR and open resection (2% vs. 3%) suggesting that MILR is effective in resection of malignant tumors.

In the absence of any randomized controlled trial comparing MILR to open resection, an increasing number of reports have noted the benefits of MILR (Reviewed in Reference 1). A recent meta-analysis comparing MILR and open resection for both benign and malignant tumors reviewed 8 nonrandomized studies reporting on 165 MILR and concluded that when performed by experienced surgeons on selected patients, short-term data seem to indicate that MILR is safe and feasible.[27] Because of the nature of the report, no details were available regarding the types of resections, the specific techniques employed, and, more importantly, a solid rationale behind the use of MILR.

Our experience constitutes the largest and most comprehensive series to date on the use of MILR for both benign and malignant liver lesions. Because the experience is restricted to a single group, we have been able to monitor changing trends and advancements in the field such as the development of newer technologies for parenchymal transection and hemostasis and, more importantly, have formulated an evolving approach to patients in need of liver resection. In a recent report,[1] we noted that the evolution of MILR at our institution has shifted our approach to the management of liver tumors, especially for benign tumors. In that report, we used specific case studies and combined our experience with that of the group at the University of Pittsburgh to demonstrate that the growing availability of these techniques can affect clinical decision-making in the management of these tumors. In other reports, we have described the hybrid technique (LAOR) for both living donor right hepatic lobectomy,[13] and for other applications,[12] and showed that this method combines the benefits of the laparoscopic procedures with the safety of open procedures, especially for surgeons with limited laparoscopic experience and expertise.

We have clearly shifted towards a more liberal use of MILR for liver tumors at our center. The percentage of liver resections performed using MILR in our group has increased from 10% in 2002 to 80% of all liver resections at the time of the current report. This dramatic paradigm change can be explained partly because of an increase in the referral of patients to our center specifically for MILR. Typically, this patient population consists of young individuals with symptomatic, benign lesions who request a minimally invasive approach. In addition, patients with malignant tumors are increasingly subjected to MILR because of the observations noted above. We currently consider MILR first as the preferred approach for all patients who require liver resection, as long as patient safety and the effectiveness of resection are not compromised.

The financial analyses of representative patients in the MILR and open cohorts provide useful insights into reimbursement patterns for surgeons, and cost implications for hospitals. Our data clearly show that there are no financial penalties to either the surgeon or the institution associated with the use of MILR, and that in fact the financial outcomes of MILR also compare favorably with those of open resections, mimicking the trends observed for clinical outcomes. In the setting of current coding and billing practices, there do not seem to be any unfavorable surgeon reimbursement patterns. Given that CPT code reimbursement is based on payment for services in a global period (90 days for these particular codes) that include postoperative inpatient and outpatient visits, equivalent surgeon reimbursement results in a higher payment to service ratio for MILR. Also, given lower THC and identical Diagnostic-Related Group (DRG) or case-rate hospital reimbursement for MILR compared with open resection, hospital operating margins are clearly higher for MILR. Moreover, the incremental costs of laparoscopic devices seem to be offset by a reduction in operative times resulting in either cost-neutral or cost-effective economics ORC for MILR and the resultant decrease in LOS decreases non-ORC costs.

The authors of the recent meta-analysis cited above conclude by stating that "results from randomized trials" are needed before definitive conclusions can be reached.[26] We think that these types of trials are highly unlikely to occur. It seems logical that given the choice, patients would be hesitant to enroll in a study in which they may be randomized to an open approach. Let us remember that the rapid adaptation of laparoscopic cholecystectomy as a replacement for its open counterpart was not influenced by randomized controlled studies. On a cautionary note, we suggest that programs intending to embark on these procedures should be well versed in complex liver surgery first, and facile with laparoscopic techniques second. We propose that surgeons with minimal laparoscopic skills adopt the hybrid technique we have described for all cases, beginning with wedge resections of peripheral lesions and with surgical management of cystic lesions. As the surgeon and the operative team acquire more familiarity with laparoscopic devices and techniques, a gradual shift towards hand-assisted techniques may be helpful. We have shown that these procedures combine the safety of open procedures with the benefits of minimally invasive surgery. Finally, as more advanced skills are acquired, the pure laparoscopic technique can be used more frequently particularly with peripheral and cystic lesions. Patient safety should come first, and therefore the surgeon's level of comfort should dictate the technique used. By adapting this type of gradual transition to MILR, a learning curve will be avoided. Open resection should be performed whenever the surgeon does not think that MILR is a reasonable alternative based on either his/her laparoscopic skills, or the nature and location of the lesion.

We think that this field will continue to advance and that, eventually, most liver resections will be performed utilizing a spectrum of MILR techniques. This will require that surgeons are satisfied that the risks to the patient associated with MILR are at most equivalent to those of open resection. This particular requirement will further necessitate the development of safer devices for the parenchymal transection of the liver, especially for the control of major vascular and biliary structures. In addition, a more generalized shift towards MILR will also require an increased recognition by surgeons that MILR is associated with less morbidity and better cosmesis than open procedures. We hope this report will contribute to this development. In the meantime, groups such as ours will continue to apply these techniques with the conviction that patients derive significant benefit from minimally invasive procedures when compared with their open counterparts and that great incisions do not necessarily define great surgeons.

CONCLUSIONS

In this report, we present a compilation of MILR for varying extents of resection for different types of both benign and malignant tumors including patients with fibrosis/cirrhosis, at a single institution. We have provided an account of the evolution of these procedures at our center and a discussion of the various MILR techniques employed. This study allows us to compare MILR directly with open resection in matched cohorts. We have shown that both clinical and financial outcomes for MILR compare favorably with those of the open standard technique. Therefore, our data suggest that MILR of varying magnitudes is safe and both clinically and cost effective for the management of both benign and malignant lesions.

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REFERENCES

1. Koffron A, Geller D, Gamblin TC, et al. Laparoscopic liver surgery: shifting the management of liver tumors. *Hepatology*. 2006;44:1694–1700.
2. Clancy TE, Swanson RS. Laparoscopic radiofrequency-assisted liver resection (LRR): a report of two cases. *Dig Dis Sci*. 2005;50:2259–2262.
3. Lefor AT, Flowers JL. Laparoscopic wedge biopsy of the liver. *J Am Coll Surg*. 1994;178:307–315.
4. Koffron A, Rao S, Ferrario M, et al. Intrahepatic biliary cystadenoma: role of cyst fluid analysis and surgical management in the laparoscopic era. *Surgery*. 2004;136:926–936.
5. Katkhouda N, Hurwitz M, Gugenheim J, et al. Laparoscopic management of benign solid and cystic lesions of the liver. *Ann Surg*. 1999;229:460–466.
6. Gloor B, Ly Q, Candinas D. Role of laparoscopy in hepatic cyst surgery. *Dig Surg*. 2002;19:494–499.
7. Gagner M, Rheault M, Dubuc J. Laparoscopic partial hepatectomy for liver tumor [Abstract]. *Surg Endosc*. 1992;6:99.
8. Gagner M, Rogula T, Selzer D. Laparoscopic liver resection: benefits and controversies. *Surg Clin North Am*. 2004;84:451–462.
9. Mala T, Edwin B. Role and limitations of laparoscopic liver resection of colorectal metastases. [Review] *Dig Dis*. 2005;23:142–150.
10. O'Rourke N, Fielding G. Laparoscopic right hepatectomy: surgical technique. *J Gastrointest Surg*. 2004;8:213–216.
11. Cuschieri A. Laparoscopic hand-assisted hepatic surgery. *Semin Laparosc Surg*. 2001;8:104–113.
12. Koffron AJ, Kung R, Affenberg G, et al. Laparoscopic liver surgery for everyone: the hybrid method. *Surgery.* In press.
13. Koffron A, Kung R, Baker T, et al. Laparoscopic-assisted right lobe donor hepatectomy. *Am J Transplant*. 2006;6:2522–2525.
14. Schmandra TC, Mierdl S, Hollander D, et al. Risk of gas embolism in hand-assisted versus total laparoscopic hepatic resection. [Comparative Study] *Surg Technol Int*. 2004;12:137–143.
15. Schmandra TC, Mierdl S, Bauer H, et al. Transoesophageal echocardiography shows high risk of gas embolism during laparoscopic hepatic resection under carbon dioxide pneumoperitoneum. *Br J Surg*. 2002;89:870–876.
16. Palmer M, Miller CW, van Way CW III, et al. Venous gas embolism associated with argon-enhanced coagulation of the liver. *J Invest Surg.* 1993;6:391–399.
17. Belghiti J, Guevara OA, Noun R, et al. Liver hanging maneuver: a safe approach to right hepatectomy without liver mobilization. *J Am Coll Surg*. 2001;193:109–111.
18. Strasberg SM. Nomenclature of hepatic anatomy and resections: a review of the Brisbane 2000 system. *J Hepatobiliary Pancreat Surg*. 2005;12:351–355.
19. American Medical Association. *Current Procedural Terminology (CPT)*. Chicago, IL: American Medical Association; 2007:205–206.
20. JN, LL, SW. *Mastery of Endoscopic and Laparoscopic Surgery.* 2nd ed. Philadelphia: Lippincott Williams and Wilkins; 2005.
21. Leventhal JR, Kocak B, Salvalaggio P, et al. Laparoscopic donor nephrectomy 1997–2003: lessons learned with 500 cases at a single institution. *Surgery*. 2004;136:881–890.
22. Samama G, Chiche L, Brefort JL, et al. Laparoscopic anatomical hepatic resection. Report of four left lobectomies for solid tumors. *Surg Endosc*. 1998;12:76–78.
23. Dulucq JL, Wintringer P, Stabilini C, et al. Laparoscopic liver resections: a single center experience. *Surg Endosc*. 2005;19:886–891.
24. Fong Y, Jarnagin W, Conlon KC, et al. Hand-assisted laparoscopic liver resection: lessons from an initial experience. *Arch Surg*. 2000;135:854–859.
25. Yamashita YI, Hamatsu T, Rikimaru T, et al. Bile leakage after hepatic resection. *Ann Surg*. 2001;233:45–50.
26. Rudow DL, Brown RS Jr, Emond JC, et al. One-year morbidity after donor right hepatectomy. *Liver Transpl*. 2004;10:1428–1431.

27. Simillis C, Constantinides VA, Tekkis PP, et al. Laparoscopic versus open hepatic resections for benign and malignant neoplasma—a meta-analysis. *Surgery*. 2007;141:203–211.

Discussions

Dr. Steven M. Strasberg (St. Louis, Missouri): Now that this MIS approach to liver surgery has the imprimatur that goes along with presentation at this meeting, predictably many surgeons will attempt such liver resection. So let's stop for a minute to ask what this means for surgery. In a recent paper discussing innovative procedures, we examined how widespread introduction of operations such as laparoscopic cholecystectomy was followed by unexpected, unpredicted, major complications to patients. Minimal access major liver surgery has all the attributes of an innovative procedure and arguably should be treated as such. Major complications will undoubtedly occur with these operations. The question is not whether but what complications, with what frequency, and what pathogenesis. Notably we observed that large mandatory registries were better at detecting uncommon but serious complications than randomized controlled trials, because it is extremely difficult to randomize the large number of patients needed to find infrequent but serious complications. So the question is, are we going to go down the same path or have we learned from the past? This is an ideal time to establish a registry of major laparoscopic liver resections so that we will know at the earliest moment what the outcomes are when the procedure begins to be done widely. This is an issue I raise for the consideration of the surgical leaders that compose the society. A registry would also have the effect of encouraging participants to be well prepared before embarking on this type of surgery. Adequate skills and preparation are going to be at the core of producing results in terms of safety achieved by this group achievable across the country, and patient consent procedures should be part of that preparation.

Moving on, I think it is also necessary to point out that this study once again proves that surgery can advance greatly through a process of iteration, often by the interactive efforts of 1 or 2 dedicated groups such as occurred in liver transplantation. That is not to take away from other approaches but it is important to recognize and appreciate the contributions to the development of surgery made by this route.

Dr. Koffron, can you tell us in more detail what were your complications and what was their severity? Did you have any near disasters, and how were they handled? What was done to ensure that the procedures were sound oncologically? Finally, what would you personally emphasize to those who will be leaving here wanting to establish programs in laparoscopic major liver surgery?

Dr. Alan J. Koffron (Chicago, Illinois): Thank you, Dr. Strasberg, for those kind words. I will address the questions in a slightly different order than asked.

With regard to intraoperative near misses, we, of course, having performed 111 lobectomies, experienced near misses of almost all types. First of all, we noticed CO_2 embolus in 2 patients. Only 1 patient had hemodynamic instability, which was managed well by our anesthesiologist and by halting the surgery and desulflating the abdomen. While the literature suggests CO_2 embolus occurs frequently, we have not experienced clinically evident CO_2 embolus in other patients, possibly because of our methods of liver transection.

In terms of hemorrhagic complications, we have experienced stapler failures. There are surgeons in the audience that witnessed a left lobectomy where a staple failed while dividing the middle and left hepatic veins. In addition, we experienced a similar event while dividing the right hepatic vein and right portal vein. Fortunately, these problems were noticed immediately and laparoscopically addressed. None of these cases were converted to open, largely because of readily available laparoscopic vascular instruments and an experienced nursing team.

These events highlight what I would like to emphasize, that before embarking upon this type of surgery, we feel, as with any complex surgery, having a team that is familiar with case and emergency technical conduct makes the difference for both the patient and the surgeon. For all of these near misses, I benefited from a surgical nursing team that would either hand me a laparoscopic vascular clamp, a preformed suture or some other device that allowed me to control and repair it almost immediately. In summary, dealing with near misses is clearly team dependent, and I will emphasize that conservative increases in resection magnitude fosters team comfort and preparation.

An equally important question was raised regarding cancer principles. In our series, we began approaching malignancies laparoscopically with the firm notion that we had a very low threshold for not performing surgery laparoscopically if we thought we were going to breech oncologic principles, whether it was surgical margins, assessment of lymph nodes, biliary ducts, et cetera, and only took on those cases initially where undoubtedly a safe and effective oncologic resection would be performed. We have also avoided hilar cholangiocarcinomas, as we feel that this neoplasm has a high likelihood of being inappropriately managed laparoscopically. And again, at any point in time during these surgeries if we felt like there would be a positive margin or breaching of the tumor during extraction, we would not use that particular minimally-invasive approach, or have converted to open techniques.

Specifically addressing postoperative complications, I will break those down into procedurally related, acute, and late.

Procedurally related complications, our manuscript states that biliary leaks were not greater than the open cohort at 2.7% versus 4% for the opens. We think this is largely due to our method of parenchymal transection and careful attention to avoiding that complication, especially during the birth and growth of this type of surgery. I alluded to hemorrhagic complications, but all events were addressed intraoperatively and our observed laparoscopic transfusion rate was less than open, suggesting hemorrhage was not a significant problem. We did not have to reoperate on anyone for delayed bleeding.

Non-procedurally related complications were very minimal. We attribute this to the fact that most of our patients went home the following day. Our average length of stay for right hemihepatectomy was 1.7 days, possibly abrogating the incidence of deep venous thrombosis, pneumonias, and things of that nature.

The minor complications, such as port site infections were similar to that we have noticed in our laparoscopic nephrectomy experience, around 1%. Late complications were rare; where we noticed only 2 incisional hernias in hand assisted laparoscopic patients, occurring greater than 1 year post-surgery.

It is interesting that even in the cirrhotic patients, we did not experience hepatic decompensation or the development of ascites following MILR. In contrast, we did have 2 patients in the open cohort that decompensated following lobectomy, and later had to undergo transplantation for rescue.

Obviously, the best way to know the true complication rates would be through a randomized controlled trial comparing laparoscopic versus open. But we doubt that that will occur, as we would think people would not want to enroll in a trial where they may be randomized to open.

Dr. Ronald W. Busuttil (Los Angeles, California): Since your procedure basically had a low conversion rate, minimal complications, outcomes that appear to be equal or superior to open technique, lower length of stay, reduced cost and greater profit margins, when would you recommend an open procedure other than for hilar carcinoma, which you already mentioned?

The second question is, you didn't stratify in your manuscript the outcomes in regards to cancer recurrence in those patients who either have metastatic colorectal or who have primary HPC.

The third question, how do you propose this very exciting technology be expanded to the hepatobiliary surgeons in the community and in the states so that we avoid some of the pitfalls we saw when laparoscopic cholecystectomy was started – for instance, the large incidence of bile duct transsections, et cetera? This is so much more of a complex procedure, we can imagine that the complication rate in those who do not have the vast experience that you have would certainly be prodigious, to say the least.

Dr. Alan J. Koffron (Chicago, Illinois): In answer to you first question regarding our recommendations for an open approach. Currently, we use MILR in about 80% of liver resections. Those 20% that we perform open, are largely hilar cholangiocarcinoma, which, as you know, is a very complex operative endeavor even in simple patients. Second, open is considered in those situations where tumor size is so great that even with hand assistance (manipulating the tumor in order to dissect the vena cava, et cetera), risk of tumor rupture may be prohibitive. Tumor disruption is one of the things that we are very careful to avoid during manipulation of the tumors or extraction. Also, and this goes back to Dr. Strasberg's near miss question, if the tumor is adherent or near a major vascular structure that must be maintained for the remnant liver viability, we would employ an open approach.

Our tumor recurrence rate was 2%. In other words, 6 patients recurred in these 300 patients, 103 of which were for malignancy. One patient experienced recurrence of cholangiocarcinoma at the cut surface, 1 year after lobe resection of a peripheral, 3 cm lesion. Four cirrhotic patients experienced de novo recurrence of hepatocellular cancers. And one was a local recurrence of a colorectal adenocarcinoma. Fortunately, and this is after 26 months of mean follow-up, we have not had more recurrences. I think our low recurrence rate is due to our conservative approach, gaining experience with benign lesions before we embarked upon resecting malignancies using this technique.

Lastly, with regard to major complications in people that are starting this type of surgery, I hope our series provides an example of how to approach this in a safe fashion, starting with small lesions, cystic lesions, and increasing to greater magnitudes of resection. As your team becomes familiar and confident in you and this approach, this will then make large resections, where biliary injuries and catastrophic vascular injuries are more likely to occur, safer endeavors.

Dr. Jean C. Emond (New York, New York): The 30 years of progress in liver surgery were a result of improved respect for anatomy parenchymal sparing, leading to almost artistic sculpturing of the liver. Many of the efforts that have been published and shown in videos represent horribly destructive and non-anatomic approaches. Your approach, in my opinion, shows the way to marry the excellence of the open surgery to the minimum access, which people in my generation didn't even dream of attempting.

I think living donor liver transplantation is on the cusp of either going away or else perhaps growing through minimally invasive methods, as happened for renal donation. Do you see this as a possibility?

Dr. Alan J. Koffron (Chicago, Illinois): That is a great question, and in fact, much of what I learned during my experience with live donor surgery in general has allowed me to apply some of these techniques to the laparoscopic methods, particularly the transection, trying to make it very similar to open surgical sculpting, as it were.

I think that through the use of the laparoscopic assisted open resection or hybrid, I think more transplant centers can apply this and hopefully gain more patient acceptance of the donation process.

Again, portions of the procedure are done laparoscopically to the surgeon's comfort level, and then through an incision that is placed over Cantlie's line, that portion of the donation which is particularly worrisome or past the surgeon's comfort level can be done using standard open techniques and a healthy, functional graft can be removed through that incision.

Dr. Myron E. Schwartz (New York, New York): I wonder whether you feel that in the future there will be a problem for people trying to learn to do liver surgery laparoscopically who don't have the experience doing open liver surgery for some period of time with a good sense of the 3-dimensional anatomy in their heads. How do you think this will play out?

Dr. Alan J. Koffron (Chicago, Illinois): That is a concern that many people have raised since the genesis of MILR. How does this disseminate in surgery in a safe fashion?

It is our belief that training and credentialing of surgeons requires strong familiarity and experience with open hepatobiliary surgery first, so that when everything is done with minimal access, as you might say, you have preemptively identified the anatomy, and therefore can guide a liver surgery team that can help you through difficult problems and cases.

Dr. Kelly M. McMasters (Louisville, Kentucky): I have to ask the question: Has the minimally invasive approach changed your indications for operation for benign tumors? You had 177 benign lesions and 103 malignant, and that is a ratio that would be much different than what we would see in many other centers where a much smaller number of benign lesions would usually be resected in that series.

Dr. Alan J. Koffron (Chicago, Illinois): This is an important point that we address in the manuscript. There are a larger number of patients in the benign category, because many patients come to us seeking minimally invasive approaches for what they know is a benign lesion. Along the way, though, we have been very, very careful not to alter our clinical pathways and resect lesions because we can offer them a minimally invasive approach.

So, in summary, we maintain the same therapeutic and surgical principles in MILR and we do open resection. We are now receiving more patients, particularly benign cases in young people, that logically effect the data and distribution.